APPLICATION AND USE OF VOICE FREQUENCY REPEATERS FOR SUBSCRIBER LOOPS

CONTENTS

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors, and other interested parties with technical information for use in the design and construction of REA borrowers' telephone systems. It discusses in particular the use of voice frequency repeaters in subscriber loop applications for use in laying out new plant or in the upgrading of existing facilities to meet the objectives of modern transmission.

1.2 The emphasis on the use of the economical fine gauge cables dictates increased use of electronic amplification to reduce losses. A very substantial amount of transmission loss is associated with these gauges. Voice frequency repeaters provide a low cost, high gain method for reducing losses. In conjunction with the high return loss available with D-66 loading, repeater gains of as much as 11 db are practical. Furthermore, because a repeater amplifies both the transmit and receive signals equally well, it not only raises the transmission level for the loop equipped with a repeater, but also helps improve the transmission of the overall connection. This is not true of one-way amplification devices which are also limited as to the useful amount of gain.

1.3 The design procedure used to engineer subscriber loop plant is treated in REA TE & CM-424, "Design of Two-Wire Subscriber Loop Plant," and reference should be made to that section. This section discusses (a) some of the more important characteristics of voice frequency repeaters (b) the application considerations for terminal repeaters located at the central office and intermediate repeaters at field mounted locations and (c) the transmission performance which is expected.

1.4 The type of repeater presently used for subscriber loop applications is the negative resistance type (abbreviated hereafter as NRR) but the design is not limited to this type repeater. Repeater use a different principle of operation and which provide equal performance and meet all subscriber application requirements can be used assuming their cost is comparable. The principle of operatior NRR is discussed in paragraph 2.0 below.

1.5 For applications where the repeater will be located at the central office the NRR provides a of 7.0 db. Of this, approximately 0.4 to 0.5 db is lost in the LBO so that the total net ga: the circuit is 6.5 db both in the transmit and receive directions. In terms of miles of loaded D-6 cable this represents 8.2 miles of 22 gauge cable and 5.4 miles of 24 gauge at 1000 cps. Therefor a C.O. mounted NRR is used, circuits can be extended in length by as much as the above values and transmission objectives are still met. The corresponding d-c loop resistance by which the outside is extended amounts to approximately 1500 ohms.

1.6 For applications where the repeater is used in a field mounted location the NRR provides a g of 11 db of which approximately 1.0 db is accounted for by the loss in two LBO's. This gain represents an extension in the outside plant of 11.2 miles of 22-D-66 or 8.3 miles of 24-D-66 load cable, or 2000 ohms approximately in d-c loop resistance.

1.7 The substantial amount of NRR gain used to engineer subscriber loops is a result of the unus impedance match possible with D-66 loading and the repeater impedance and this results in in and stable gain. This is not true of the H-88 loading system, particularly in the existing H-88 p had been engineered over the years on the basis of non-repeatered applications. Because substanti tions in cable mutual capacitance, load spacing accuracy and end-sections were built-in in existin plant by design, only a limited amount of gain is advisable if the circuits are to remain free of adverse effects of hollowness, echo, singing and frequency compression.

2. PRINCIPLE OF REPEATER OPERATION

2.1 The NRR is a two-wire repeater which amplifies transmit and receive voice frequency speech signals when used in a telephone line. It is inserted in series with the line in a manner so that tip and ring d-c line continuity is maintained and d-c (or a-c) supervisory signals and ringing currents pass through the repeater. Because the impedance of the bare cable is positive while that for the NRR is negative the net effect is that circuit loss is reduced. Thus the NRR amplifies signals by the principle of insertion of negative resistance in a line.

2.2 A transformer is used within the NRR to couple the repeater to the line and it is through this coupling (or line) transformer that d-c line continuity is maintained. There are two parts to that part of the repeater which furnishes the gain. These are the "series" repeater unit and the "shunt" repeater unit which make up the complete repeater known as the gain-unit. The series repeater unit is actually in series with the line fed from the line transformer while the shunt repeater unit is across the line coupled by capacitors or a shunt transformer in series with a capacitor. The gain unit of the NRR is shown in Figure 1.

2.3 Both the series and shunt repeater units furnish gain to the circuit but do so in a different manner. For example, it is possible to use the series part of the repeater alone to provide gain but this results in a poor impedance condition at the point in the circuit where the repeater is placed so that on toll calls the echo return loss performance is low resulting in talker echo (the talker hears his own voice delayed). To maintain high return loss values and provide the most gain possible both the series and shunt repeater units are used.

2.4 The NRR amplifies both the transmit and receive paths in a two-wire circuit by the same amount (unlike four-wire voice frequency repeaters or carrier systems which effectively have separate directions of transmission). Because of this ability the NRR type repeater is called "bilateral" and it presents the same impedance when viewed from either pair of terminals. Thus, its "in" and "out" terminals are interchangeable provided that the line building-out unit (LBO) described in paragraph 2.5 below always faces the cable in terminal repeater applications. Looking into the gain-unit of the NRR when the other pair of terminals is terminated in a 900 ohm resistor in series with a two microfarad capacitor, its impedance remains essentially the same; that is, 900 ohms in series with two microfarads. Therefore the NRR can be considered to be a 900 ohm resistor but an active resistor, however, because it is also furnishing gain.

2.5 The line building-out unit (LBO) in the NRR is the remaining other important part of the repeater. It is a passive network consisting of coils, capacitors and resistors. Its sole purpose is to change the very complex impedance of the loaded cable pair which varies with frequency (and other factors) to a much simpler impedance such as a 900 ohm resistor, for example. When a cable pair is thus modified by the LBO to look like a simple 900 ohm resistor, very good performance results when the repeater gain unit is inserted in the cable because the repeater gain unit also looks like a 900 ohm resistor so that good matching is obtained throughout.

2.6 The LBO in the NRR contains a capacitor building-out (BOC) component, a resistance building-out component (BOR), a high frequency corrector (HFC) and a low frequency corrector (LFC) as shown in Figure 2. All these contribute in smoothing out the complex impedance of the loaded cable and convert it to the simple resistance value discussed in paragraph 2.5 above. For the type of NRR normally used in this section for engineering subscriber loop plant no adjustments in the LBO are required. The LBO comes pre-adjusted by the manufacturer. A different LBO is used with each type of loading. The NRR used in this section will accommodate LBO's for D-66 or H-88 loading with exchange cable.

3. REPEATER TRANSMISSION CHARACTERISTICS

3.1 The type of NRR used in this section to engineer subscriber loop plant is a two-wire transistorized unit powered from 48 volts unfiltered central office batteries with a current drain of 35 milliamperes or less per repeater unit. The repeater can operate with as low a supply voltage as 15 volts d-c with no degradation in performance. The NRR can be adjusted to give as much as 13 db gain. However, the particular types described herein can be fixed gain types providing 7.0 db for terminal applications with the unit mounted in a central office location and 11.0 db for intermediate or field mounted applications. No gain strapping is required for the fixed-gain type. The gain is two-way; that is, 7.0 or 11.0 db gain in the transmit direction and the same amount in the receive direction.

3.2 Direct-current for talking battery and dial pulsing, supervisory signals and frequency selective or superimposed d-c ringing currents are passed through the repeater without serious impairment and without the aid of auxiliary bypass equipment. Voice frequency tone signaling is improved when using NRR's because these signals are amplified the same as voice currents. NRR adds approximately 60 ohms to the overall subscriber loop resistance. This should be added to the other resistance when determining the signaling limits of the central office equipment.

3.3 The NRR will operate properly with maximum metallic direct current in the line of 40 ma. The gain of the repeater is not affected by d-c loop current variations and the same gain is obtained even when the d-c loop current is zero as, for example, when testing over the lines. For field mounted applications the surrounding temperature should not exceed -20°F. or 140°F.

3.4 The repeater provides the same gain regardless of the talkers speech level. It does not clip and distort very weak or very loud speech signals. Because its maximum undistorted single frequency power output is +16 dbm, the repeater unit can be routinely tested directly with normal 0 dbm test tone input power level without compression. The gain of the NRR is effective across the entire voice frequency band and beyond so that testing for gain can be performed at any frequency of interest using standard 600 or 900 ohm test equipment.

3.5 The NRR will work properly when calls are made from one repeatered loop to another repeatered loop, when calls are made through VNL+2 toll connecting or EAS trunks also equipped with NRR's, other type voice frequency repeaters in a back-to-back fashion, or carrier derived circuits.

3.6 Signaling is still possible through an NRR repeatered loop when the power to the repeater is cut off. This is because the d-c line continuity is still maintained through the line transformer in the NRR although there will be no amplification. When the power is off the circuit loss increases by approximately the amount of repeater gain. Thus, during an emergency communication can still be provided.

3.7 Based on past experience, the protection characteristics of NRR's in withstanding lightning surges are excellent. Also they have extremely low maintenance based on the experience of several thousand repeater units.

4. APPLICATION CONSIDERATIONS

4.01 Subscriber loops in buried plant 1700 and 2000 ohms and greater outside plant d-c loop resistance, D-66 loaded, require NRR's (1500 ohms and greater for H-88 loading) in order to meet transmission objectives. When the loop has "long" end-sections a repeater is used starting at 1700 ohms. With "short" end-section loops the repeater is used starting at 2000 ohms. For aerial cables the above values of resistance must be reduced by 12 percent.

4.011 A "short end-section" D-66 loaded loop is defined as a loop having the maximum number of loading coils which can be placed in that length. The subscriber end-section in a short end-section loaded loop can be between 2000 to 4500 feet. If the subscriber end-section in a short end-section loaded loop is less than 2000 feet it should be built-out with a .030 microfarad building-out capacitor.

4.012 A "long end-section" D-66 loop is defined as a loaded loop with as little as 4500 feet end-section after the last loading point but not exceeding 12 kf including all unisolated bridged taps.

4.013 For existing H-88 loaded plant to be repeatered with NRR's the maximum subscriber end-section length after the last loading point, including all unisolated bridge taps, should not exceed 6000 feet. Structural return loss measurements for the existing portion are furthermore recommended to verify that the as-built plant is free of impedance irregularities. Observing this precaution with existing H-88 plant will help eliminate the substandard transmission performance shown in Figure 13 when the NRR's are installed. It is recommended that the structural return loss measurements be made at the ACD stage, so that if the measured plant performance is not found to be sufficiently adequate the 4.5 db NRR gain recommended in paragraph 4.023 should be reduced to between 2.5 to 3.0 db. The structural return loss measurements are described in REA TE & CM-445, "How to Make Structural Return Loss Measurements," and reference should be made to that Section

4.02 C.O. Mounted Repeaters

4.021 Use terminal NRR's with 7.0 db gain using the distance range in Table I for one uniform gauge D-66.

4.022 Use terminal NRR's with 7.0 db gain using the resistance range in Table III for mixed gauges D-66.

4.023 For existing H-88 plant a NRR with 4.5 db gain should be placed at the central office starting at 1500 ohms. This will provide adequate transmission up to 2400 ohms. For assuring adequate bandwidth and for avoiding hollowness or near singing conditions it is strongly recommended that end sections be kept at 6000 feet total or less.

4.03 Field Mounted Repeaters

4.031 Use intermediate NRR's with 11.0 db gain using the distance range in Table II for uniform gauges and the resistance range in Table III for mixed gauges D-66.

4.032 Intermediate repeaters with H-88 are not recommended because on repeatered loop-to-loop calls their use results in frequency compression which degrades the transmission. This is shown in Figure 11 for ideal H-88 outside plant. Gains higher than 4.5 db are not recommended because of possible hollowness and near singing effects. In actual practice performance can be worse due to deviations in cable mutual capacitance, spacing deviations and other factors. Figure 13 shows the performance with such plant. The response is highly irregular, conversation sounds hollow and the quality of transmission very poor. The circuit is on the borderline of instability.

4.04 For a NRR operating in a terminal central office location one LBO only is required of the same type as the loading system used. The LBO must face the cable side of the repeater as shown in Figure 2(b)

... faces the central office equipment. A jumper wire is used to connect the tip an[d] ... the tip and ring of the central office equipment. This jumper wire is known as a ... and is shown in Figure 2(b). The dummy LBO must always be facing the C.O. side of the NRR. I[f] ... regular LBO become interchanged by error circuit echo return loss performance will be poor ... repeater may be unstable or sing in addition. Terminal NRR's are mounted at the central office ... the cable pair at the MDF and the LLA equipment and d-c powered from 48-volt nominal ... batteries.

For a NRR operating at an intermediate or field mounted location two LBO's must be used of the same type as the loading system used. This is shown in Figure 2(c). The "dummy" LBO is not used for these applications. The end-sections of the loaded cable outside plant facing each side of the repeater should be ... feet (0.5 end-section) or as close to this value as possible. This assures that no adjustments will be necessary to the NRR LBO in capacitance (CBO) or resistance (BOR).

Field mounted NRR's can be located at any convenient point in the line such as the middle third of the electrical loss of the circuit so that a number of repeater units can be powered and housed in the same cabinet. The repeaters can be powered by normal A-C to D-C converter arrangements and should be equipped with a standby battery. For those areas where temperatures lower than -20°F. will be encountered the cabinet should be equipped with a heater to maintain normal repeater equipment operating temperatures. For those areas where temperatures higher than 100°F. will be encountered the equipment cabinet should be well ventilated. Local power charges and availability may be a factor to consider before deciding on this method of powering.

For field mounted NRR's another arrangement can be used which consists of extending a separate cable pair to power the repeaters from the 48-volt central office batteries. The power feed pair tip and ring conductors at the central office and at the repeater location should be connected together in order to keep the loop resistance low and extend the feed distance. A booster feed power supply in the central office can be used in series along with the normal 48-volt office batteries for elevating the voltage and extending the feed distance further where this is needed. This booster feed power supply can be either 24- or 48-volts depending on the particular requirements and it is inserted in series with the ring side of the 48-volt central office batteries. Chart I also shows the arrangement for a number of NRR units, for a feed of 300 ohms and feed voltages of 48, 72 or 96 volts. As indicated in paragraph 3.1 above, approximately 15 volts are required at the repeater location to assure proper repeater operation.

Two different arrangements are shown in Chart II for connecting the 48 or 24-volt booster supply ... terms ... central office batteries for the power feed. Most types of NRR presently available have their case ground isolated from the battery goound terminal so that the simplex arrangement method B can be used to advantage because this method is less susceptible to damaging effects due to longitudinal surges from lightning, power system failures, earth potential effects, etc.

When using the power feed arrangement of paragraph 4.07 above to power a number of repeater units it should be kept in mind that the voltage at the repeater location will rise when removing some of the repeaters from the line. If this voltage is higher than 60 volts at the repeater location it may damage the remaining repeaters. A small power resistor can be used in place of each NRR being removed (approximately 200 ohms ± 20 percent, 2 watts) to prevent the voltage from rising.

4.08 Field mounted NRR's should be protected with normal 300 volt carbon protection on their tip and ring "in" and "out" terminals and also on the d-c power feed. Because protection experience on field mounted NRR's is lacking it would be advisable to consider installing supplementary low voltage protection. Where the A-C to D-C converter method is used to power field mounted NRR's the protection considerations discussed in REA TE & CM-822, "Electrical Protection of Carrier Equipment," for the A-C side of the converter must apply.

4.09 For signaling reasons a long line adapter must be used on all buried plant loops 1700 ohms (and greater) outside plant d-c loop resistance and 1500 ohms (and greater) with aerial cable plant. For signaling and transmission (telephone set transmitter) a 24-volt booster power supply must be used (in series aiding with normal C.O. 48-volt battery voltage) with buried plant loops 1700 ohms and greater and 1500 ohms and greater for aerial cable plant. A long line adapter is required when the booster power supply is used for inserting this voltage in the line. The 24-volt booster is adequate up to 3000 ohms buried plant outside plant d-c loop resistance. For loops beyond this a 48-volt booster must be used for transmission reasons. The 48-volt booster can also be used starting at 1700 ohms in lieu of the 24-volt booster. Used in preference to the 24-volt booster it aids both the signaling and the transmission. A long line adapter must also be used with the 48-volt booster for inserting the voltage in the line.

4.10 Reliable ringing is obtained up to 4500 ohms d-c loop resistance where the number of ringers on the line do not exceed four.

EXPECTED REPEATERED CIRCUIT PERFORMANCE

... transmission properties of a subscriber loop which are of direct importance for local and DDD ... are:

... at 1000 cps

.2 Circuit Bandwidth
.3 Evenness of Response
.4 Sidetone Level
.5 Stability
.6 Noise
.7 Crosstalk
.8 Echo Return Loss
.9 Singing Point

echo return loss and singing point performance are of primary importance on connections involving the network.

2 The net loss to the farthest subscriber which is allowable at 1000 cps is 10 db including all losses and repeater gain(s). The 10 db loss is the worst net loss for the longest loop. All other loops lower (better) than this value. Typical net losses are shown in Figures 3-10.

3 Where D-66 loading is used circuit bandwidth will be good even for loops with as much as 12 KF end-sections. For loops with "short" end-sections (one-party service) which are fully loaded the bandwidth will be extremely good because the 1000 cps and 3400 cps response is practically identical. Modern) type telephone sets transmit well up to 3400 cps so that they are used to advantage. The bandwidth of pical D-66 loaded loops with NRR's and various end-section lengths is shown in Figures 3-10.

.31 Long D-66 loops with NRR's under the condition of one long loop calling another such long loop are shown in Figures 8-10. In Figures 8 and 9 the repeaters are back-to-back at the central office. Figure 8 the deviation in the 1000 to 3000 cps response (the difference in the values of insertion loss tween these two frequencies) is approximately 2 db. As the amount of gain becomes larger or the circuit ngth becomes longer, the deviation in response becomes larger also. In Figure 9 this deviation is proximately 4 db. With the intermediate repeater configurations at 11 db gain each, respectively, and th LBO's on each side of the repeater, the deviation becomes still larger. Reference to Figure 10 shows is to be 5 db between 1000 to 3000 cps. This performance for subscriber loop plant is very good.

.32 The discussion in paragraph 5.31 above leads to this important consideration. With D-66 loading, because the cutoff is approximately 4600 cps, it is possible to use the very fine gauges to advantage and with several intermediate E-6 repeaters and as many as six LBO's and still obtain circuits having good bandwidth. In other words, under the worst conditions (long repeater loop calling another long peater loop) <u>frequency compression</u> does not become a problem with D-66 loops because of the wide band vailable. With other types of loading systems, particularly with the H-88, this will not be the case. ere, severe frequency compression results. This is shown in Figure 12 where two intermediate NRR's are own. Whereas the insertion loss at 1000 cycles is only 7.5 db at 3000 cps it is 24 db. This is with <u>ieal</u>, 3000 feet end-sections (curve A), <u>ideal</u> load coil spacing and <u>ideal</u> cable mutual capacitance. In e case of end-sections of 7.5 and 12 kilofeet the 3000 cps loss is <u>31.3</u> and 39.5 db, respectively.

5.33 H-88 loading will more likely be encountered with existing outside plants. It will therefore be more realistic to also account for (a) the load spacing deviations which will be the rule rather han the exception (b) the higher mutual cable capacitance furnished under older cable specifications and c) the possibility for some moisture in the cable. Because of these factors which are realistic for xisting H-88 loaded plant the frequency response shown in Figure 12 will be further degraded. At best, he resulting circuit bandwidth will be 300 cps to around 2200-2400 cps, and this is not considered good odern-day transmission. Considering that most new types of trunk carrier equipment are being designed o provide circuit bandwidths up to 3400 cps, 2300 cps transmission would be offering the subscribers xtremely poor service.

5.4 Reference to Figures 2-10 on repeater insertion gain and frequency response indicates that the curve for the repeatered loss of the subscriber loop is rather smooth. That is, it shows no pronounced eaks and valleys. Because of this smoothness the circuits have a natural and therefore pleasing talking uality. This is also characteristic of D-66 loading although the circuits are being operated with fairly igh amounts of gain. The presence of peaks and valleys in the frequency response as was the case with ormer transmission practices produces undesirable hollowness and near singing conditions in repeatered loops in the talking condition and this is poor transmission. It is very undesirable and psychologically isturbing to the subscriber. This is shown in Figure 13.

5.5 Telephone set sidetone on the NRR design shown is low. The absence of high sidetone level contributes to natural and pleasing transmission. The use of the 96-volt talking battery does not increase sidetone levels appreciably.

5.6 Repeatered circuits with NRR's are to be unconditionally stable and this method is called the "stability design" method. This means that at no time during the progress of a call a subscriber experiences singing conditions or spurts of singing and in the idle condition no crosstalk or tones are being induced into other cable pairs. From a maintenance standpoint, with circuits using the "stability" design, little attention need be paid to the repeaters because they behave as passive elements, like cable, for example. Thus, maintenance personnel need not be particularly skilled in voice frequency repeater specialties. All the examples shown in Figures 3-10 are unconditionally stable.

5.7 Noise in subscriber loop plant is affected primarily by the type of construction used, the deg balance in the outside plant and the central office equipment and the influence characteristic power lines in the immediate area. Therefore noise is not directly the result of having repeaters i circuit. The NRR equipment used in the loop design herein is well balanced so that it does not intrc noise on its own. Such a balanced repeater merely amplifies whatever noise is already on the line by amount of the repeater gain. Design practices for avoiding noise problems are discussed in Section 4 and reference should be made to that section for details. REA TE & CM-451, "Telephone Line Noise Mitigation and Measurement," discusses procedures for solving noise problems.

5.8 Crosstalk is controlled within limits by keeping the repeater gain at the central office locatic less than 8.0 db when the cables are D-66 loaded and by the crosstalk requirements for the cable the REA PE Specifications. For intermediate repeaters the crosstalk limit is increased because of the intervening cable loss between the central office and the repeater. Therefore from a crosstalk standp the gain of pole mounted NRR's can be higher without problems.

5.9 The echo return loss (ERL) and singing point (SP) performance with D-66 loading is extremely good Figures 3-5 show typical values of ERL of as much as 28 db and 16 db for SP between 900 ohms in series with a 2 microfarad termination. ERL and SP requirements for two-wire VNL+2 toll connecting tru are 18 db and 10 db, respectively. Therefore the performance of the loop plant with respect to these parameters is at least as good and actually better using this test termination. Performance using tele- phone sets for the subscriber termination is equally good. With the loop operating at a net loss of approximately 9 db ERL is 20.5 db and SP is 12 db. At very low net loss (less than 2 db) the ERL is 16. db and SP 10 db. Performance characteristics using telephone set terminations are shown in Figure 11. For H-88 loops particularly with existing plant performance may not be adequate. Echo return loss value will be much lower, particularly the performance in the SP range at frequencies higher than 2500 cps.

TABLE I
RANGE OF DISTANCES FOR C.O. MOUNTED NRR'S
ONE UNIFORM GAUGE ONLY
EXCHANGE CABLE .083 MF/MI NOMINAL
BURIED PLANT ONLY[1]

A. D-66 WITH "SHORT"[2] END-SECTION	NRR DISTANCE RANGE		
START PLACING REPEATER AT:	7.1 MI	(37.5 KF)	24-D-66
LIMIT SAME REPEATER TO :	12.4 MI	(65.6 KF)	24-D-66
START PLACING REPEATER AT:	11.2 MI	(59.2 KF)	22-D-66
LIMIT SAME REPEATER TO :	19.6 MI	(103 KF)	22-D-66

B. D-66 WITH "LONG"[2] END-SECTION			
START PLACING REPEATER AT:	6.1 MI	(32.2 KF)	24-D-66
LIMIT SAME REPEATER TO :	10.7 MI	(56.5 KF)	24-D-66
START PLACING REPEATER AT:	9.5 MI	(50.2 KF)	22-D-66
LIMIT SAME REPEATER TO :	16.8 MI	(89.1 KF)	22-D-66

TABLE II
RANGE OF DISTANCES FOR FIELD MOUNTED NRR's
ONE UNIFORM GAUGE ONLY
BURIED PLANT ONLY[1] (3)

A. D-66 WITH "SHORT"[2] END-SECTION	NRR DISTANCE RANGE		
START PLACING REPEATER AT:	12.4 MI	(65.6 KF)	24-D-66
LIMIT SAME REPEATER TO :	15.3 MI	(80.7 KF)	24-D-66
START PLACING REPEATER AT:	19.6 MI	(103 KF)	22-D-66
LIMIT SAME REPEATER TO :	24.0 MI	(127 KF)	22-D-66

B. D-66 WITH "LONG"[2] END-SECTION			
START PLACING REPEATER AT:	10.7 MI	(56.5 KF)	24-D-66
LIMIT SAME REPEATER TO :	13.5 MI	(71.5 KF)	24-D-66
START PLACING REPEATER AT:	16.8 MI	(89.1 KF)	22-D-66
LIMIT SAME REPEATER TO :	21.4 MI	(112.8 KF)	22-D-66

NOTES
1. FOR AERIAL PLANT REDUCE DISTANCE BY 12 PERCENT
2. AS DEFINED IN PARAGRAPHS 4.011 and 4.012
3. FOUR RINGERS MAXIMUM ONLY
4. OTHER REQUIREMENTS IN PARAGRAPH 4.09 ALSO APPLY

TABLE III
RANGE OF RESISTANCE FOR C.O. AND FIELD MOUNTED NRR's
MIXED GAUGE CABLES D-66 LOADED
EXCHANGE CABLE .083 MF/MI NOMINAL
BURIED PLANT ONLY (1)

REPEATER LOCATION	D-66 LOOP END SECTION LENGTH (2)		NRR RESISTANCE R
C.O.	SHORT	START PLACING REPEATER AT: LIMIT SAME REPEATER TO :	2000 OHMS 3500 OHMS
C.O.	LONG	START PLACING REPEATER AT: LIMIT SAME REPEATER TO :	1700 OHMS 3000 OHMS
FIELD	SHORT	START PLACING REPEATER AT: LIMIT SAME REPEATER TO :	3500[3] OHMS 4300 OHMS
FIELD	LONG	START PLACING REPEATER AT: LIMIT SAME REPEATER TO :	3000[3] OHMS 3800 OHMS

NOTES

1. FOR AERIAL CABLE REDUCE RESISTANCE BY 12 PERCENT
2. AS DEFINED IN PARAGRAPHS 4.011 and 4.012
3. FOUR RINGERS MAXIMUM ONLY.
4. OTHER REQUIREMENTS IN PARAGRAPH 4.09 ALSO APPLY

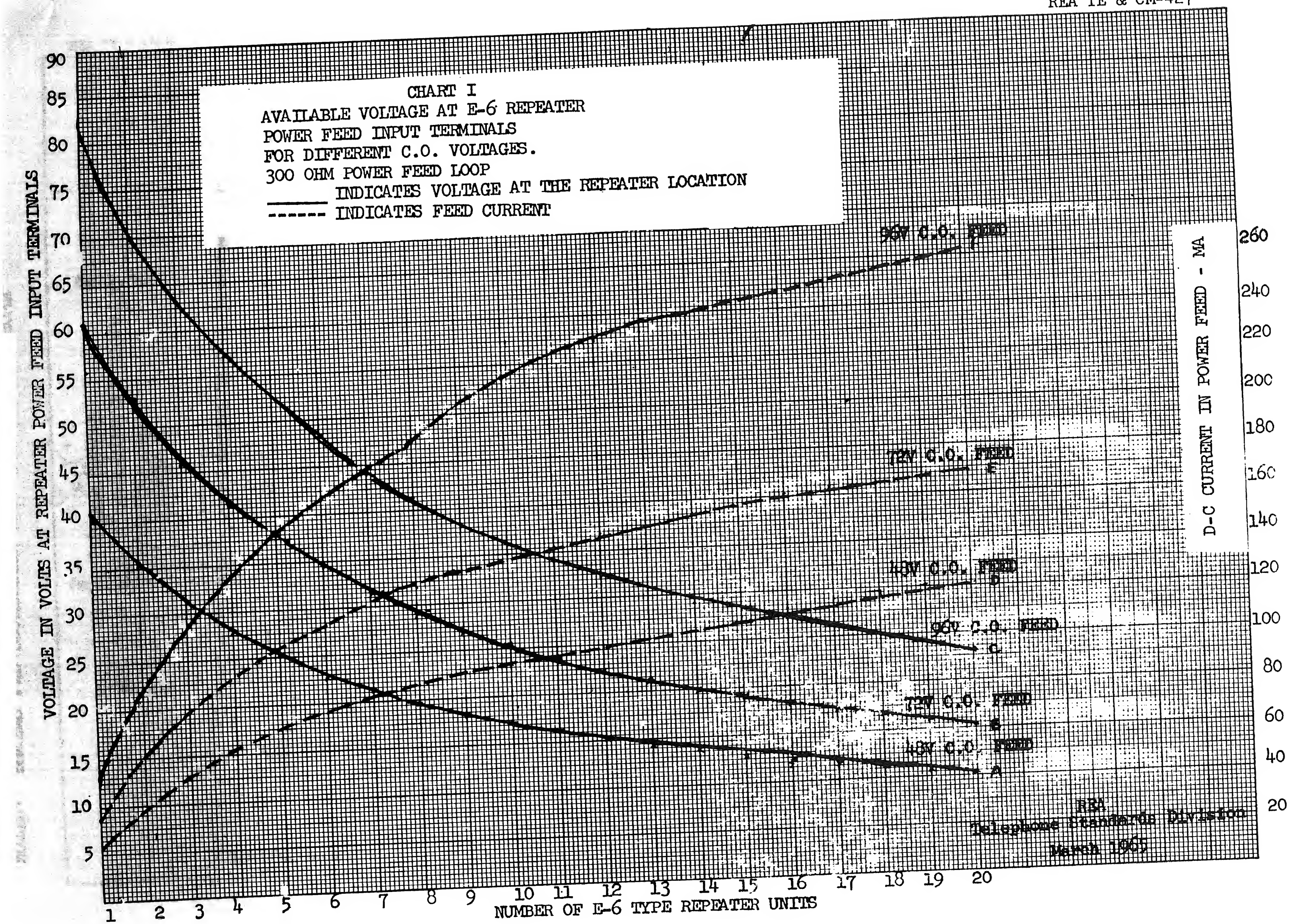
CHART I
AVAILABLE VOLTAGE AT E-6 REPEATER
POWER FEED INPUT TERMINALS
FOR DIFFERENT C.O. VOLTAGES.
300 OHM POWER FEED LOOP
INDICATES VOLTAGE AT THE REPEATER LOCATION
INDICATES FEED CURRENT
96V C.O. FEED
72V C.O. FEED
48V C.O. FEED
96V C.O. FEED
72V C.O. FEED
48V C.O. FEED
VOLTAGE IN VOLTS AT REPEATER POWER FEED INPUT TERMINALS
D-C CURRENT IN POWER FEED - MA
NUMBER OF E-6 TYPE REPEATER UNITS
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
260
240
220
200
180
160
140
120
100
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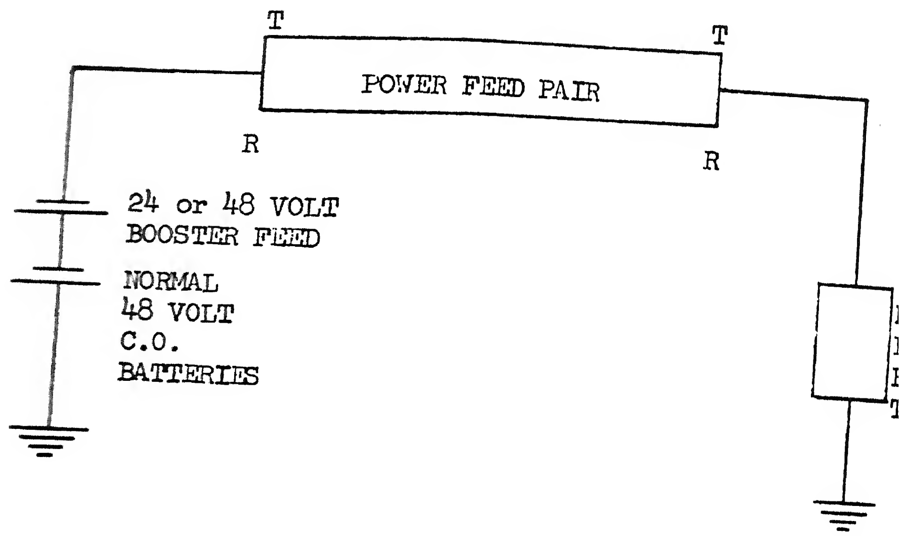
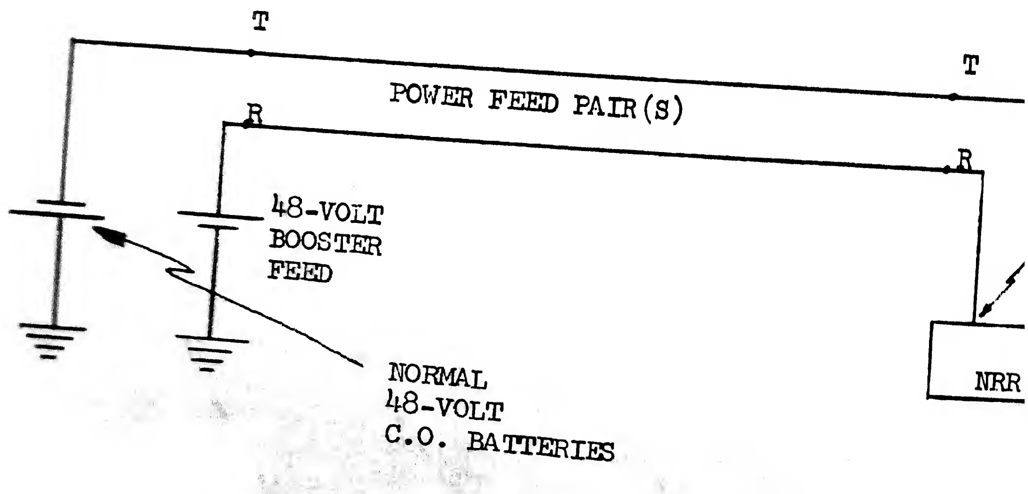
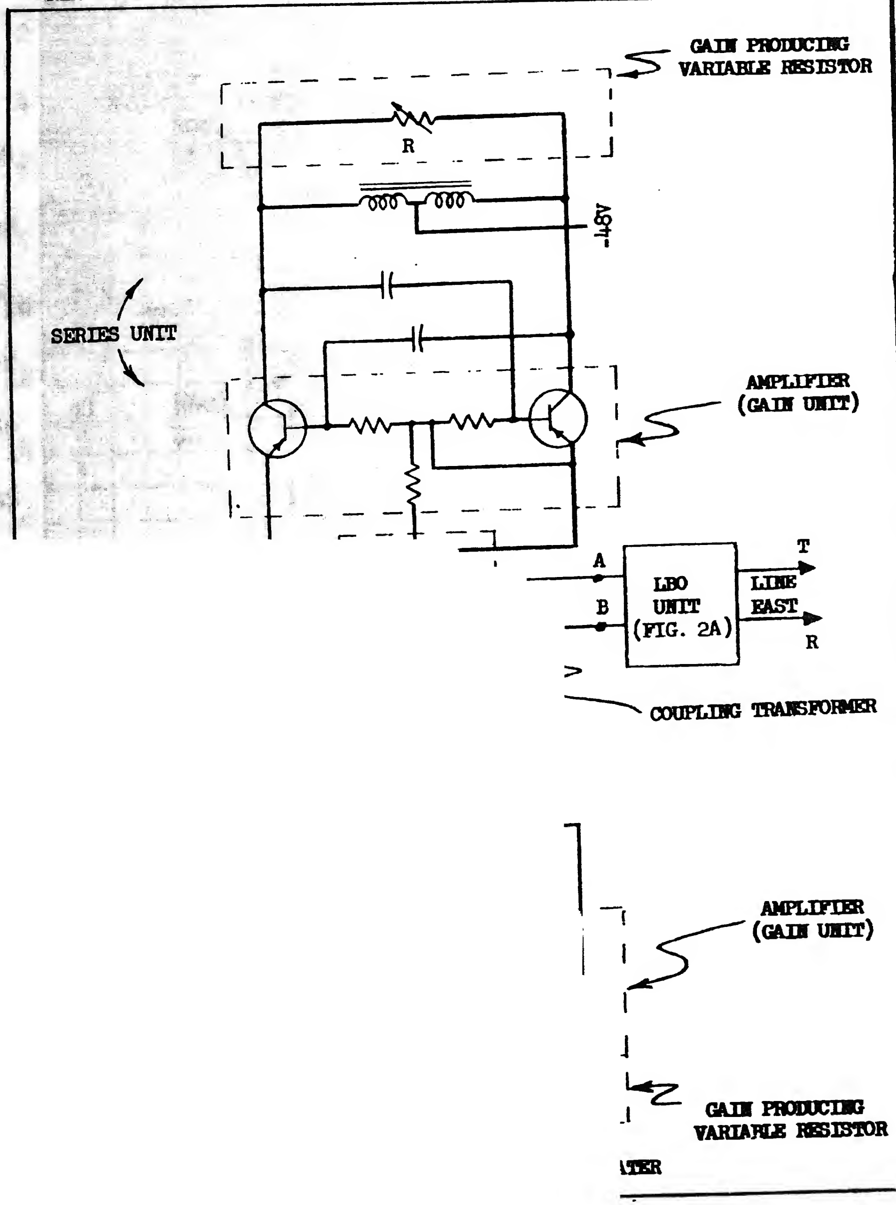
REA
Telephone Standards Division
March 1965

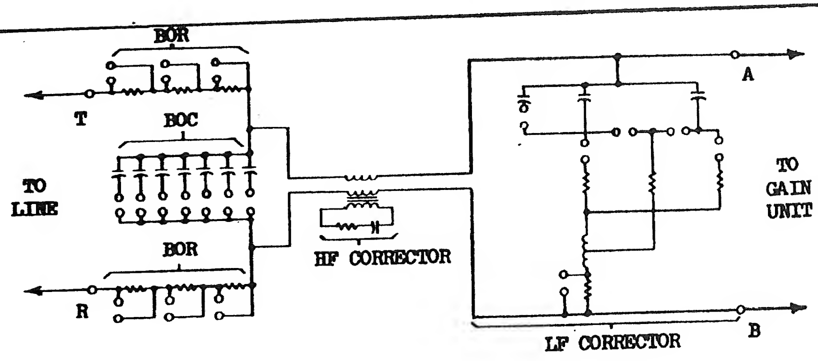
CHART II
VARIOUS POWER FEED ARRANGEMENTS
FOR POLE MOUNTED NRR's
USING SEPARATE CABLE PAIR FOR POWER FEED



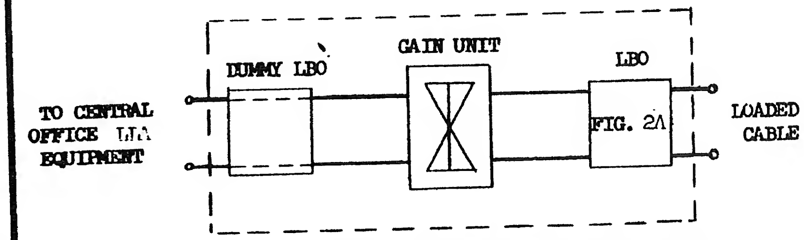
METHOD A
LONGITUDINAL FEED
NRR CASE CAN BE GROUNDED TO GROUND TERMINAL



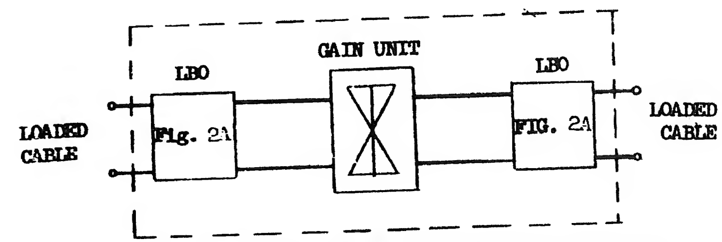




A. CONFIGURATION OF "LINE BUILDING OUT" NETWORK - LBO



B. LBO ARRANGEMENT FOR TERMINAL NRR TYPE REPEATER



C. LBO ARRANGEMENT FOR INTERMEDIATE NRR TYPE REPEATER

FIGURE 2. LBO CONFIGURATIONS

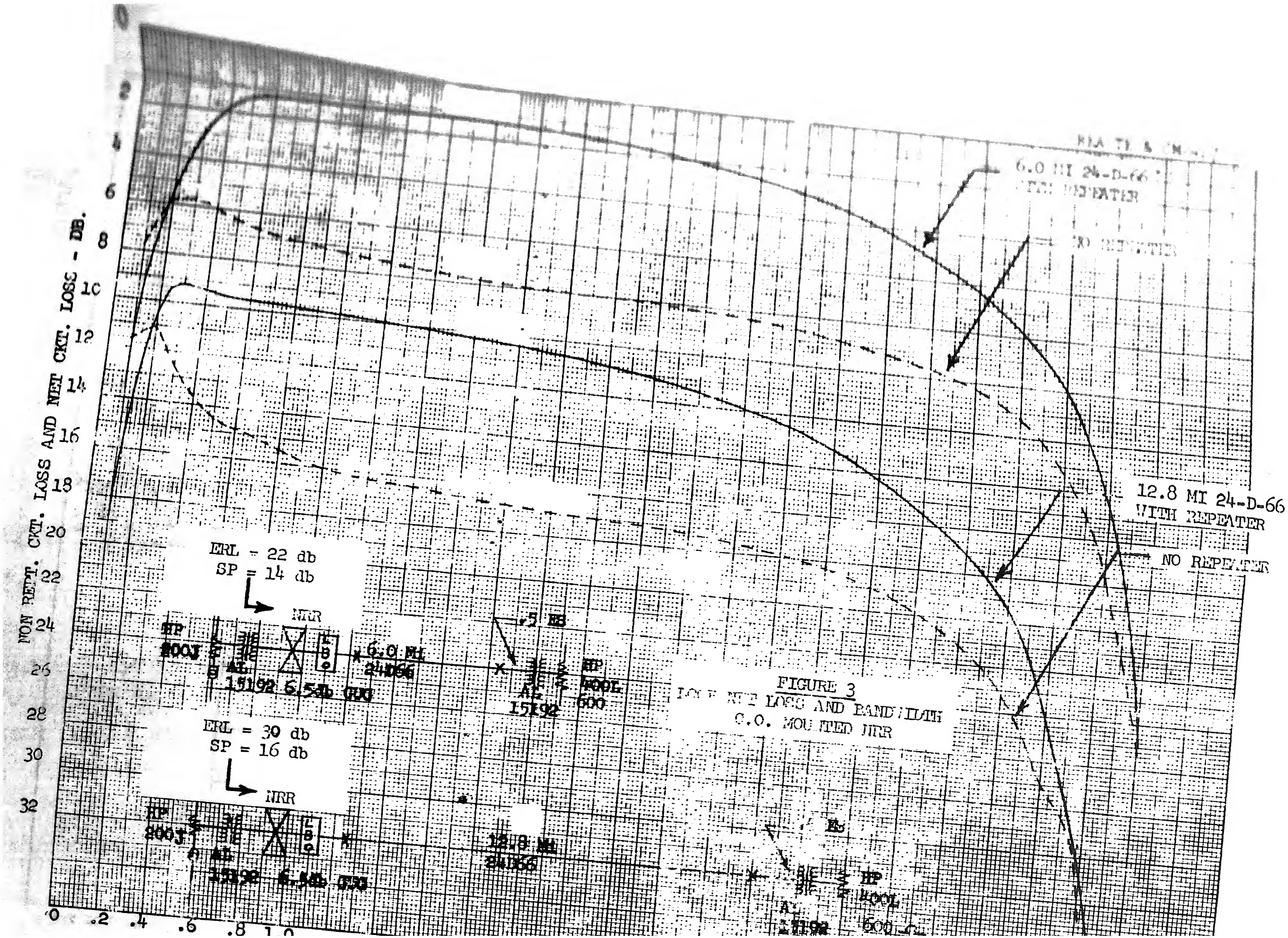


FIGURE 3
LOOP NET LOSS AND BANDWIDTH
C.O. MOUNTED NRR

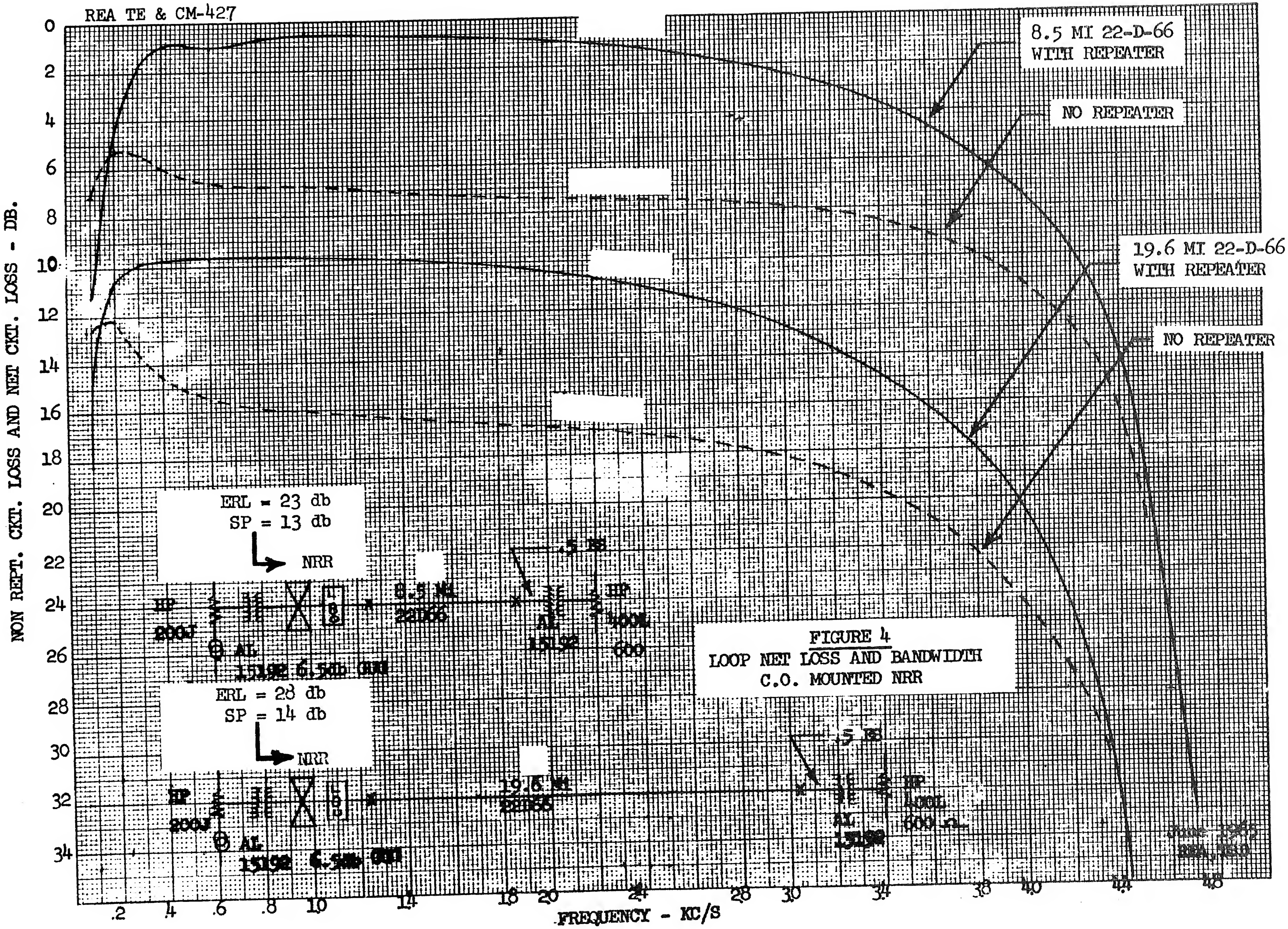


FIGURE 4
LOOP NET LOSS AND BANDWIDTH
C.O. MOUNTED NRR

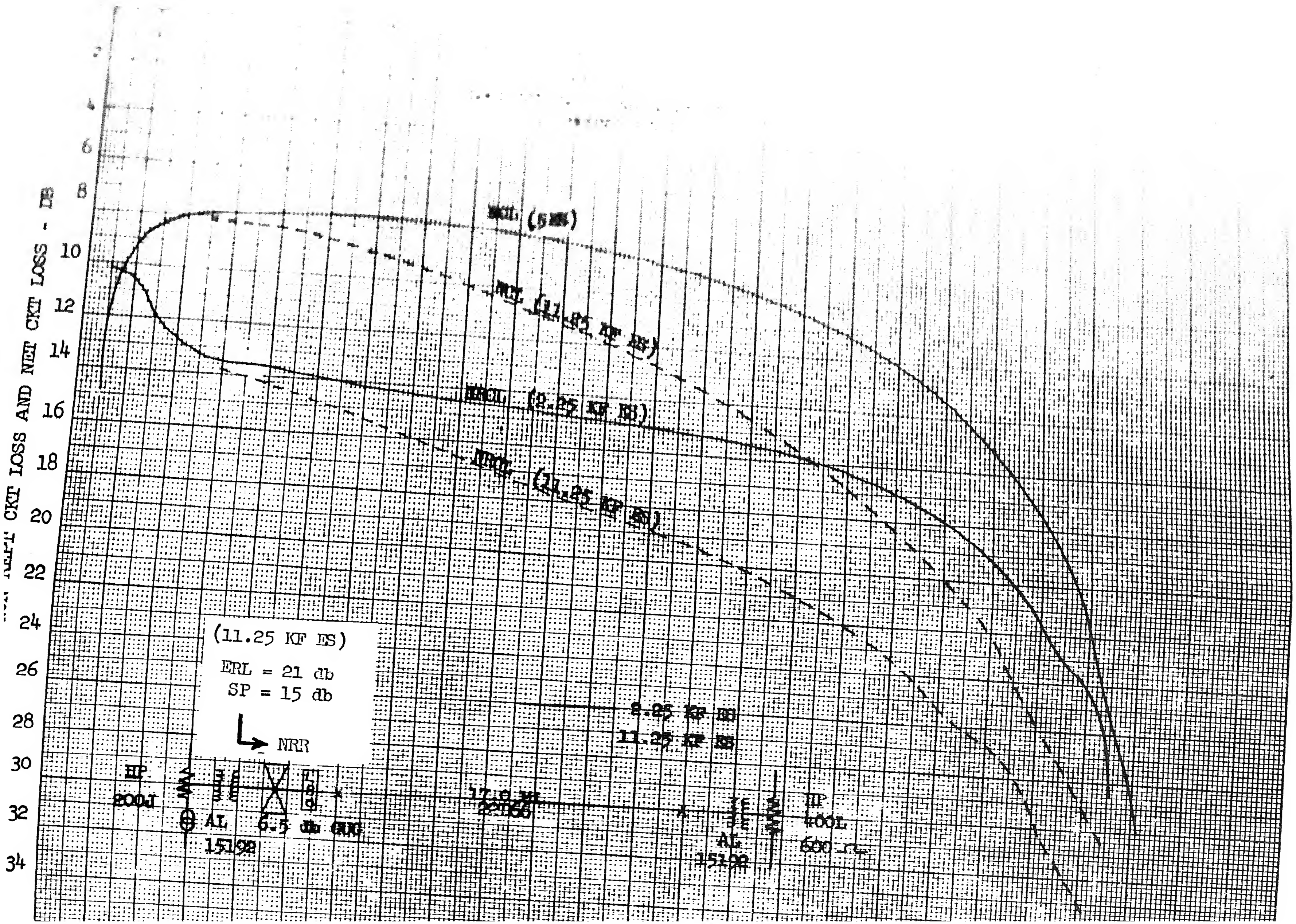
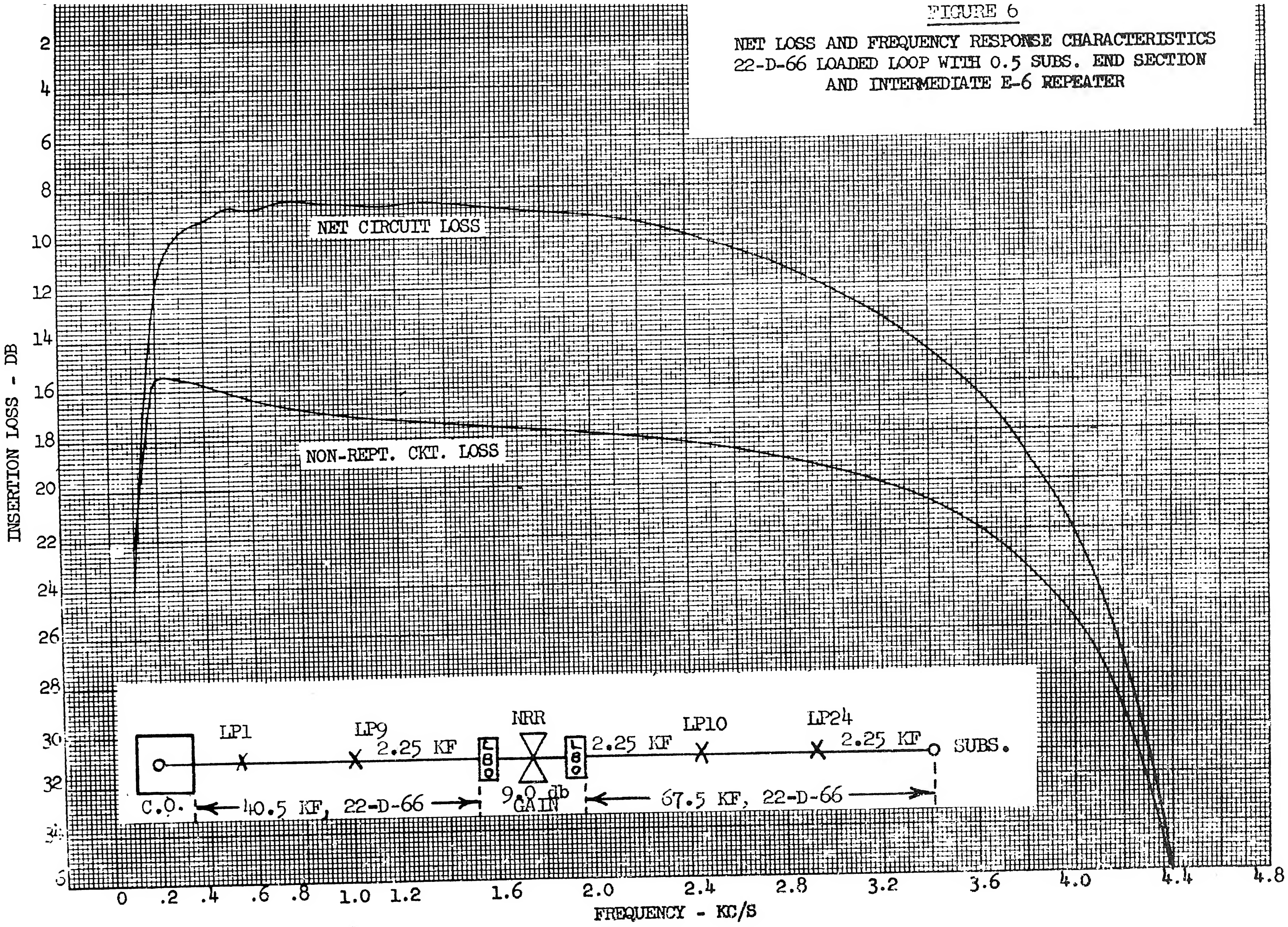
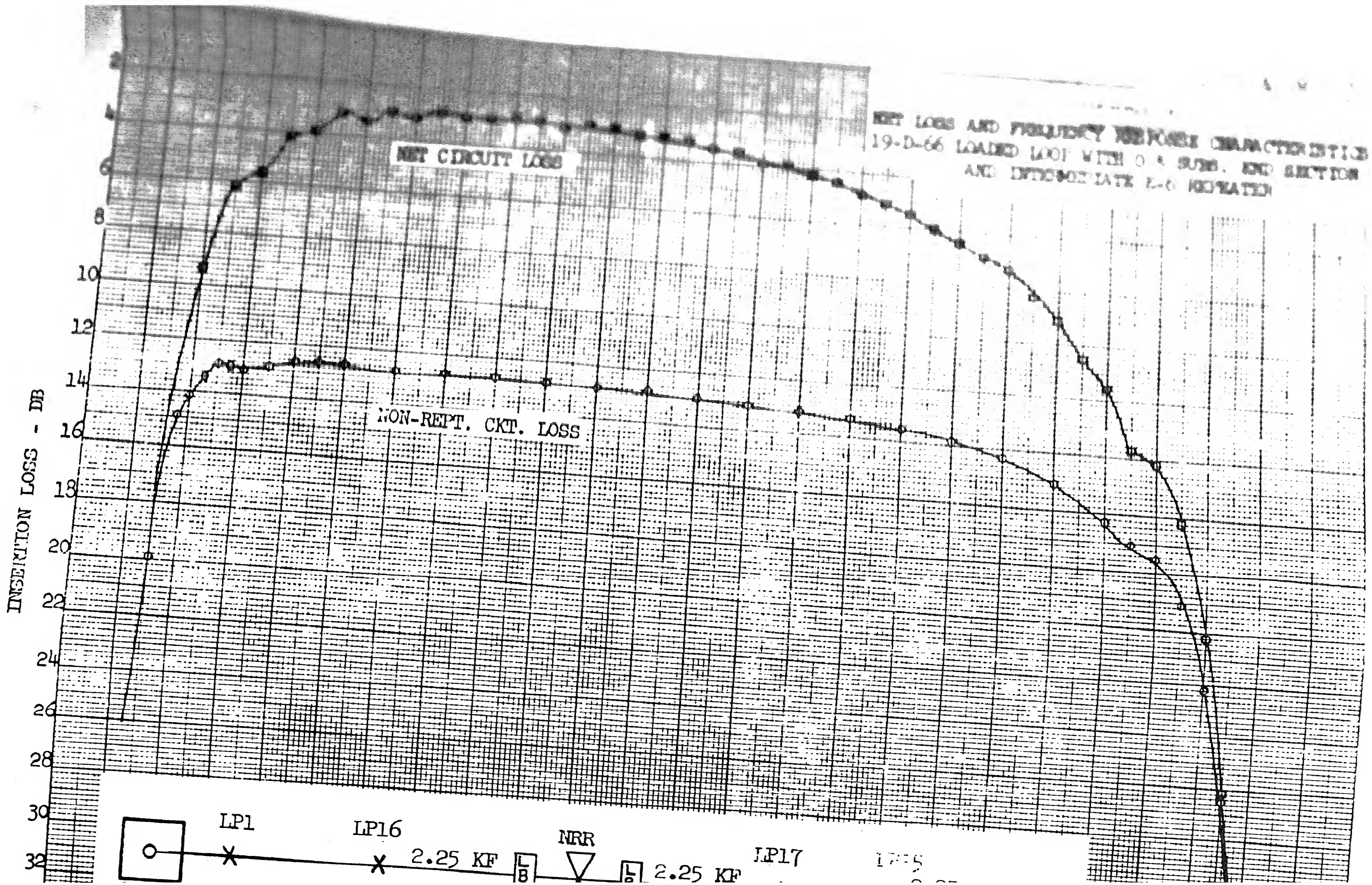

NET CKT LOSS AND NET CKT LOSS - DB
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
(11.25 KF ES)
ERL = 21 db
SP = 15 db
NRR
HP
200J
AL
15192
6.5 db
11.25 KF ES
HP
400L
600
AL
15192

FIGURE 6

NET LOSS AND FREQUENCY RESPONSE CHARACTERISTICS
22-D-66 LOADED LOOP WITH 0.5 SUBS. END SECTION
AND INTERMEDIATE E-6 REPEATER





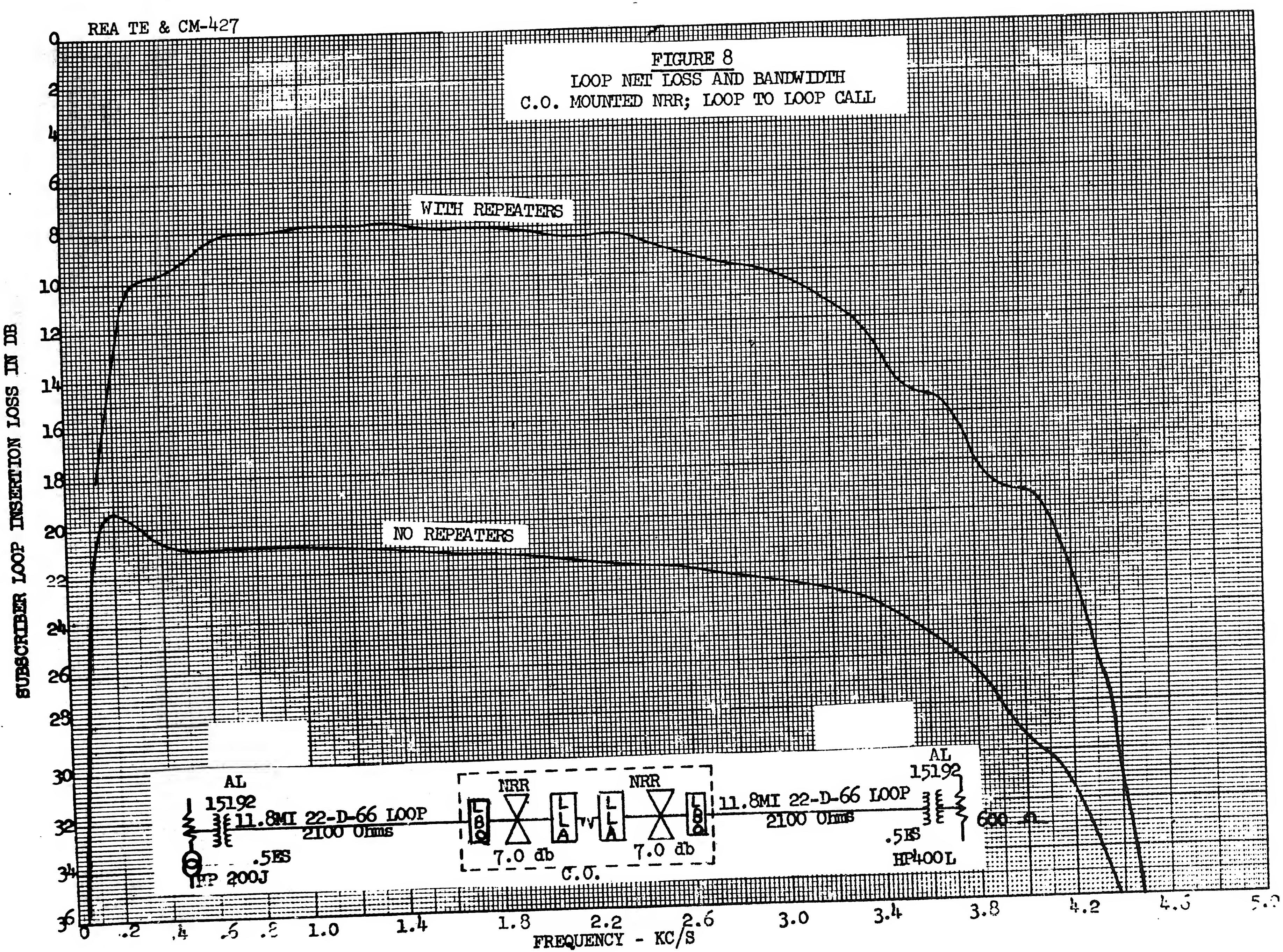
NET LOSS AND FREQUENCY RESPONSE CHARACTERISTIC
19-D-66 LOADED LOOP WITH
END SECTION
AND INTERMEDIATE E-6 REPEATER
NET CIRCUIT LOSS
NON-REPT. CKT. LOSS
INSERTION LOSS - DB
8
10
12
14
16
18
20
22
24
26
28
30
32
LP1
LP16
2.25 KF
NRR
2.25 KF
LP17

REA TE & CM-427

FIGURE 8

LOOP NET LOSS AND BANDWIDTH

C.O. MOUNTED NRR; LOOP TO LOOP CALL



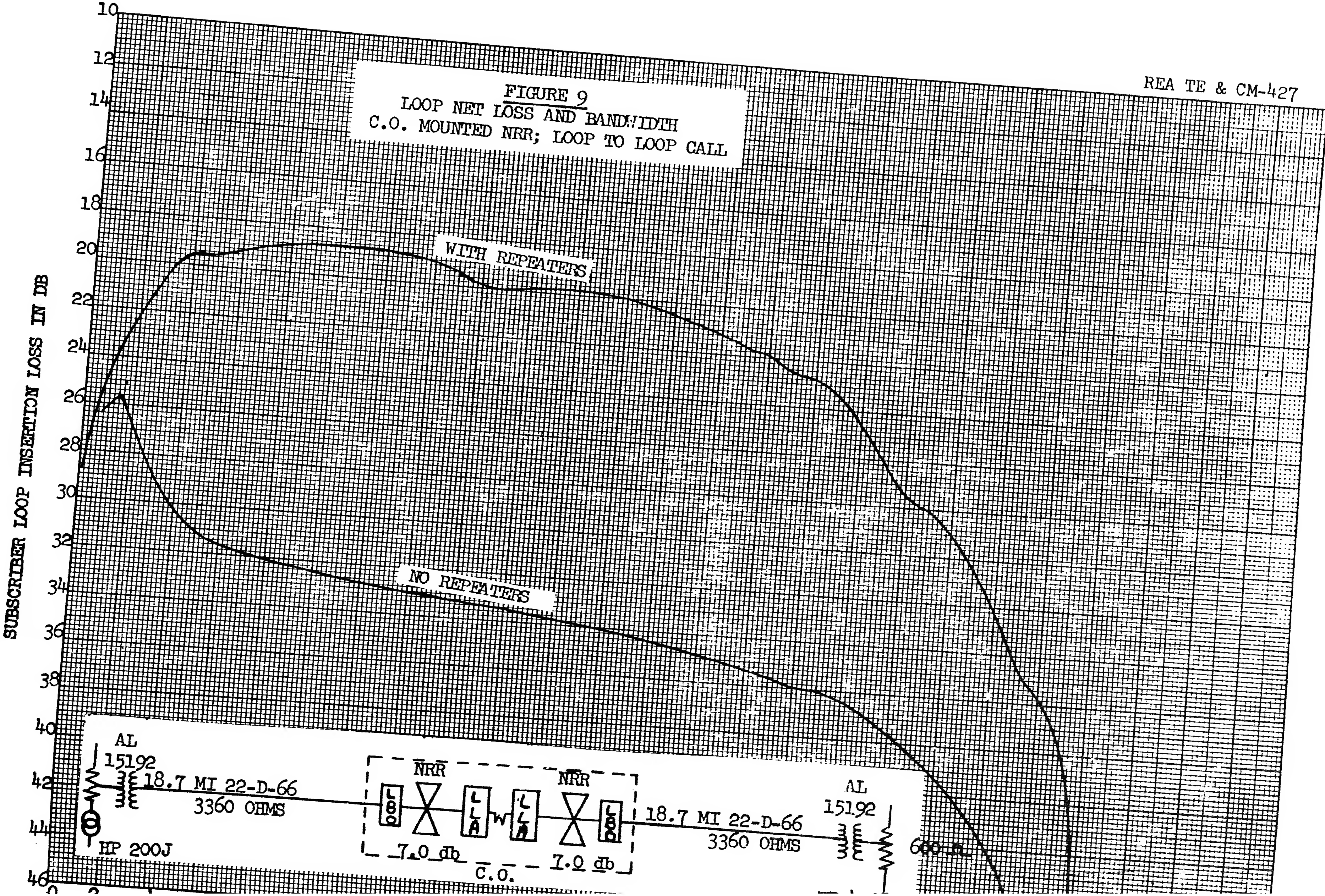


FIGURE 9
LOOP NET LOSS AND BANDWIDTH
C.O. MOUNTED NRR; LOOP TO LOOP CALL
WITH REPEATERS
NO REPEATERS
SUBSCRIBER LOOP INSERTION LOSS IN DB
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
AL
15192
18.7 MI 22-D-66
3360 OHMS
HP 200J
NRR
7.0 db
C.O.
NRR
7.0 db
18.7 MI 22-D-66
3360 OHMS
AL
15192
600 Ω

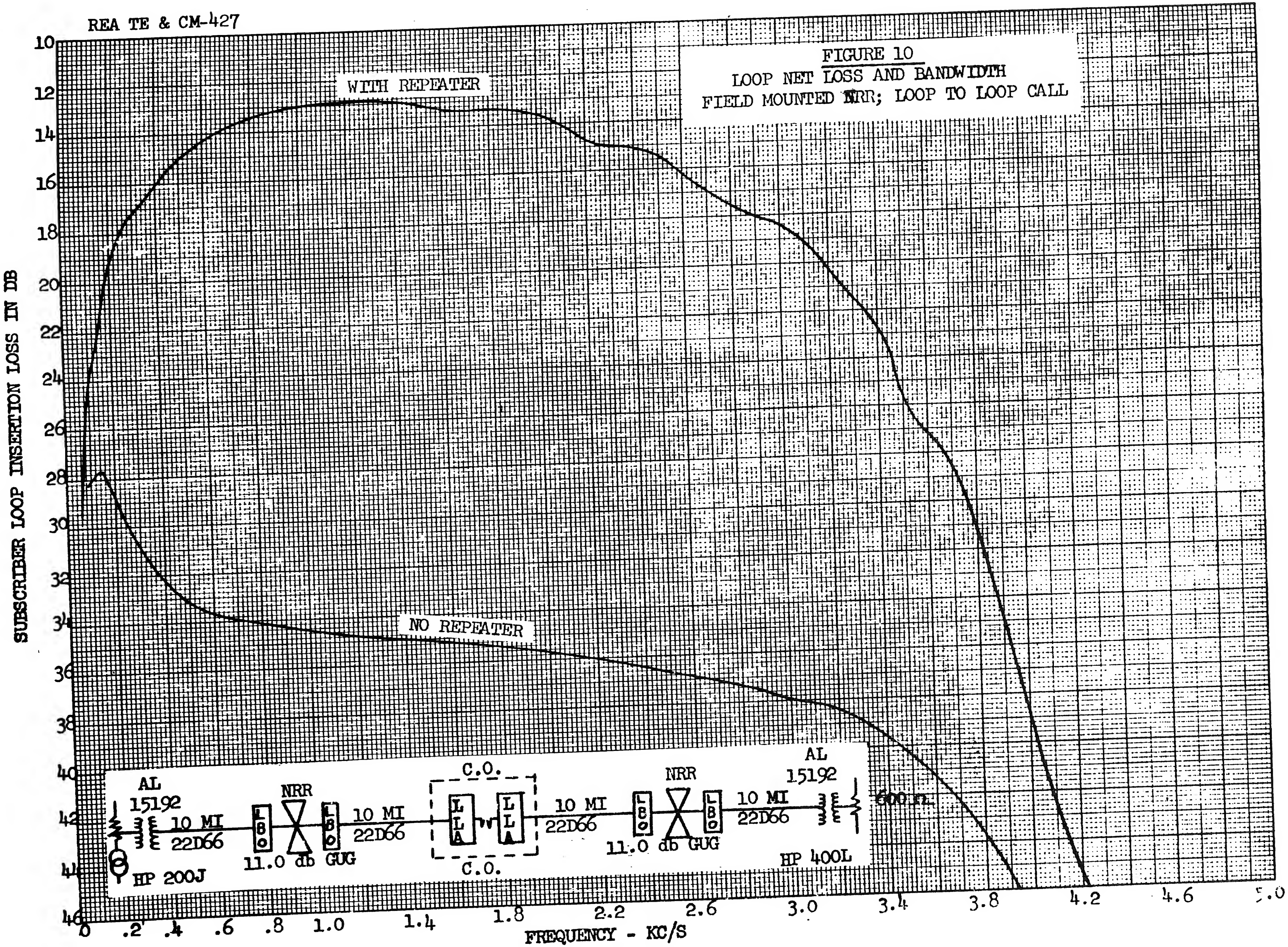
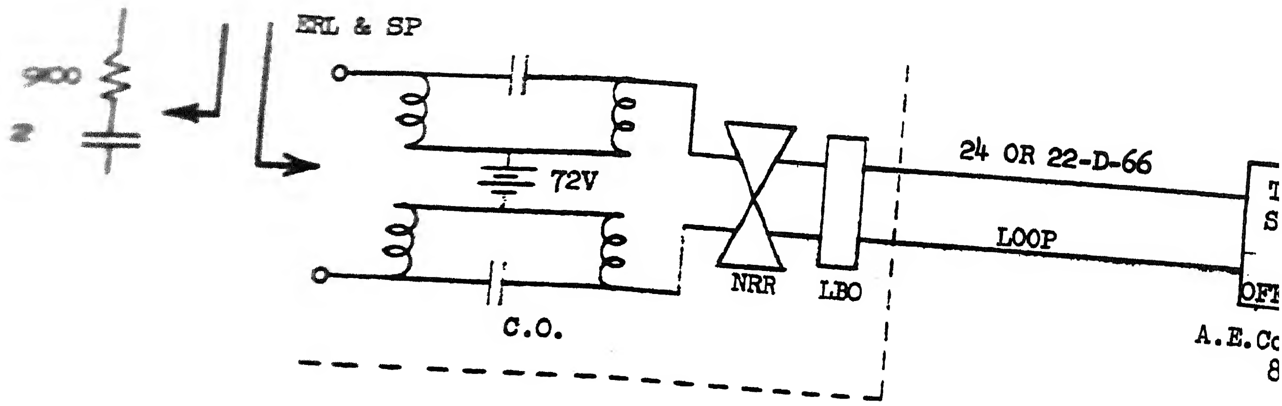


FIGURE 10
LOOP NET LOSS AND BANDWIDTH
FIELD MOUNTED NRR; LOOP TO LOOP CALL
WITH REPEATER
NO REPEATER
SUBSCRIBER LOOP INSERTION LOSS IN DB
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
FREQUENCY - KC/S
0
.2
.4
.6
.8
1.0
1.4
1.8
2.2
2.6
3.0
3.4
3.8
4.2
4.6
5.0
AL
15192
10 MI
22D66
HP 200J
L
B
O
NRR
11.0 db
GUG
C.O.
L
L
A
C.O.
AL
15192
600 Ω
HP 400L

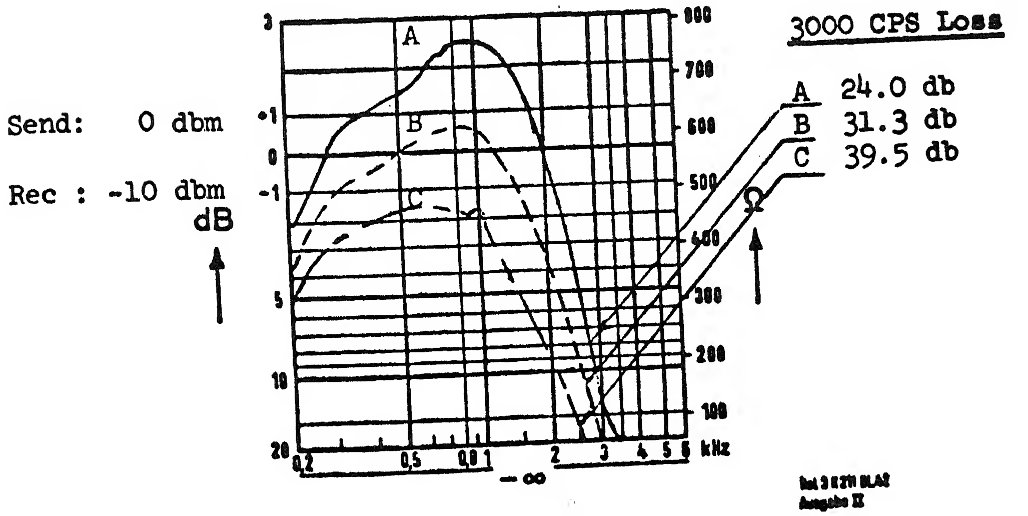
FIGURE 11
ECHO RETURN LOSS AND SINGING POINT PERFORMANCE
REPEATERED LOOP WITH TELEPHONE SET TERMINATION

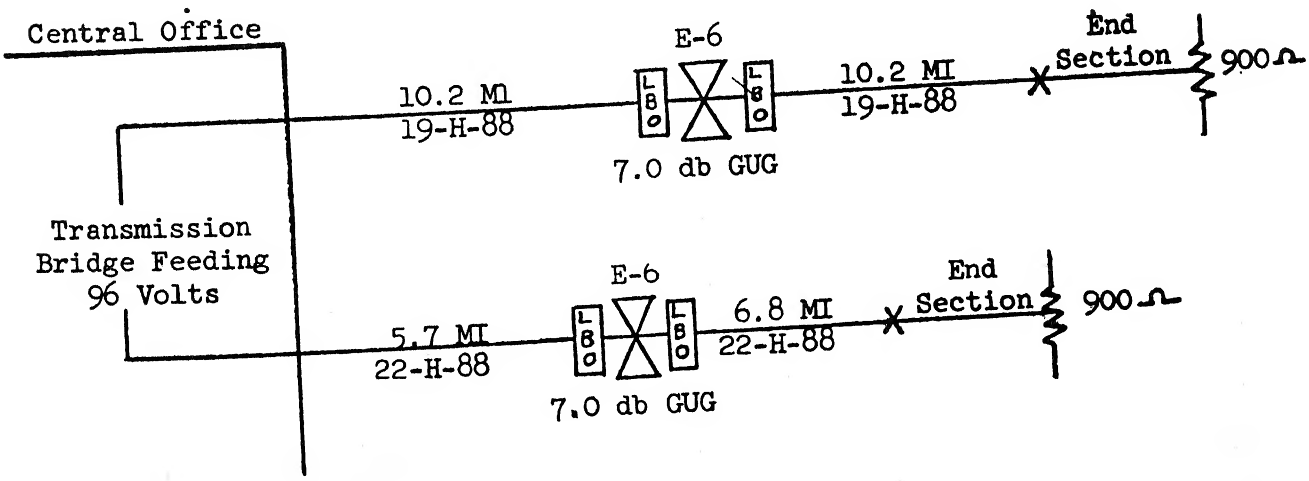


FACILITY TYPE	LOOP NET LOSS (db)	ECHO RETURN LOSS (db)	SINGING POINT db
24-D-66	10	20.5	14
24-D-66	1.7	16	10
22-D-66	9.7	18.5	12
22-D-66	2.1	16.5	12

FIGURE 12

INSERTION LOSS - H-88 SUBSCRIBER LOOPS
ONE INTERMEDIATE E-6 REPT PER LOOP
TWO LOOPS SWITCHED AT C.O. AND USING 96^V BATTERY FEED
IDEAL MUTUAL CAPACITANCE (0.083 MF PER MILE) AND IDEAL SPACING (6000')

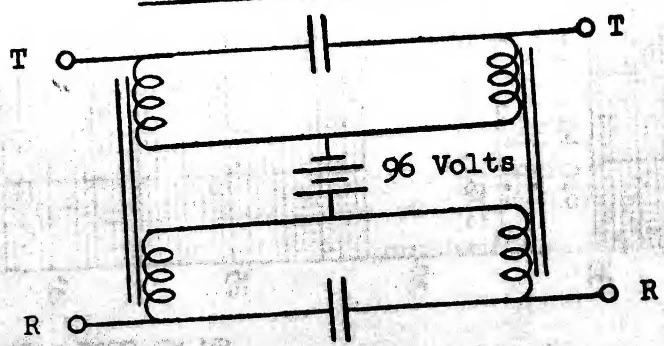




END SECTIONS

Curve A:	3,000 Feet
Curve B:	7,500 Feet
Curve C:	12,000 Feet

TRANSMISSION BRIDGE



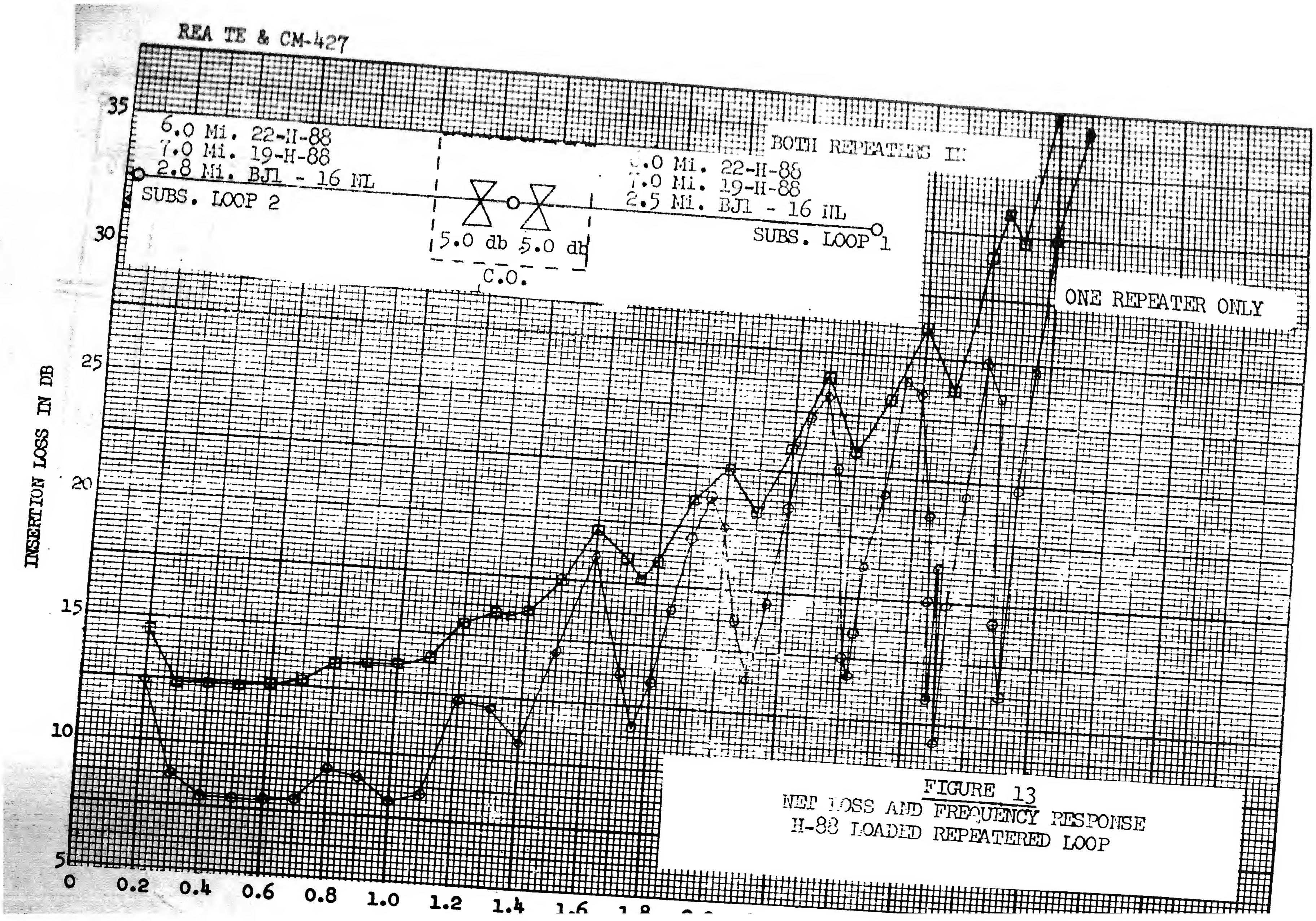


FIGURE 13
NET LOSS AND FREQUENCY RESPONSE
H-88 LOADED REPEATERED LOOP